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(54) Digital code for line transmission

(57) A method of transmitting information encoded into a binary digit stream in which successive groups of N binary digits are translated into corresponding groups of M binary digits, where $M > N$, the translation being accomplished according to at least the following rules:-

a) only M-bit groups having a disparity not exceeding $\pm (M/2 - 2)$ are allowable;

b) no M-bit group having more than n consecutive ones or zeros at the beginning or end is allowable, where $n = M/2$;

c) no zero disparity M-bit group having more than $n-2$ consecutive ones (zeros) at the end and $n-1$ consecutive ones (zeros) at the beginning is allowable. The resulting M-bit code will have the unique features of

1) peak digital sum in every group occurs at the same digit position;

2) maximum run of like digits between successive groups only occurs with the last digit of the run always in the same digit position.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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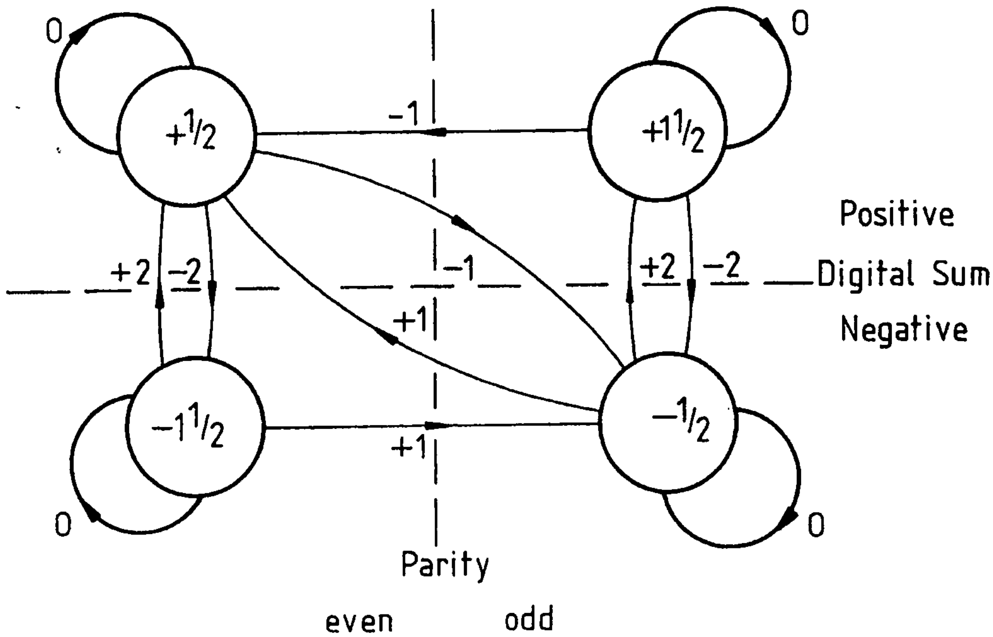
0
0
+1/2
-1
+11/2
Positive
+2
-2
-1
+2
-2
Digital Sum
Negative
+1
-11/2
+1
-1/2
0
0
Parity
even
odd

Fig.1.

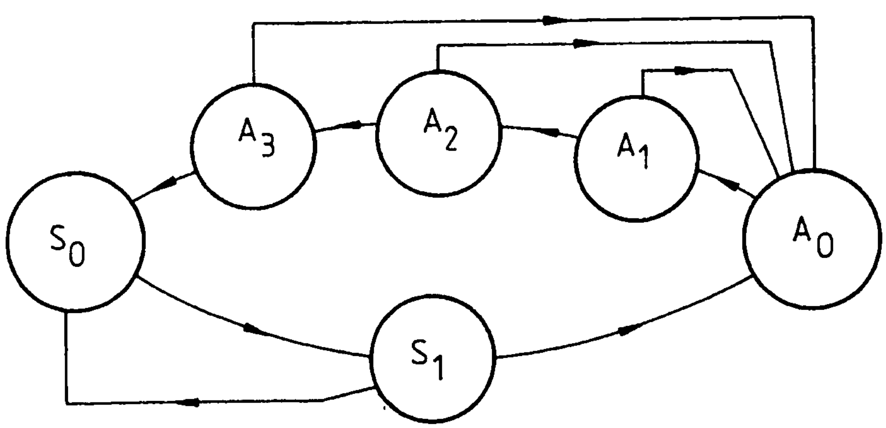
A3
A2
A1
S0
A0
S1

Fig.2.

i) Zero Disparity Output Groups with alternative Coding for Auxiliary Channel and Parity Count d.c. Control:

Input (7 digits)	Output (8 digits) Mode 1	Parity Count d.c. Weight		Mode 2	
0000000	00101101	(0)	(0)	11010010	Aux Chan
0000001	00101110	(+2)	(−2)	11010001	Parity Count d.c. Control
0000010	01111000	(+4)	(−6)	10000111	
0000011	01101010	(+2)	(−2)	10010101	
0000100	01100110	(+4)	(−4)	10011001	
0000101	01100101	(+2)	(−2)	10011010	
0000110	01010110	(+2)	(−2)	10101001	
0000111	10100110	(+2)	(−2)	01011001	

Fig. 3.

ii) Zero Disparity Groups with Unique Coding:

Input	Output
0001000	00111100
0001001	00111010
0001010	00111001
0001011	00110110
0001100	00110101
0001101	00110011
0001110	00101011
0001111	00100111
0010000	01110100
0010001	01110010
0010010	01110001
0010011	01101100
0010100	01101001
0010101	01100011
0010110	01011100
0010111	01011010
0011000	01010101
0011001	01010011
0011010	01001110
0011011	01001101
0011100	01001011
0011101	01000111
0011110	11000011
0011111	11000101
0100000	11000110
0100001	11001001
0100010	11001010
0100011	11001100
0100100	11010100
0100100	11011000
0100110	10001011
0100111	10001101
0101000	10001110
0101001	10010011
0101010	10010110
0101011	10011100
0101100	10100011
0101101	10100101
0101110	10101010
0101111	10101100
0110000	10110001
0110001	10110010
0110010	10110100
0110011	10111000

Fig.3.

iii) ± 1 Disparity Group Pairs : 4/5

Input	Output Mode 1	Parity	Count d.c. Weight	Output Mode 2
0110100	00001011	+2	−2	11110100
0110101	00001101	+4	0	11110010
0110110	00001110	+2	+2	11110001
0110111	00011100	0	−4	11100011
0111000	00011010	+2	−2	11100101
0111001	00011001	+4	−4	11100110
0111010	00010011	0	−4	11101100
0111011	00010101	+2	−2	11101010
0111100	00010110	0	0	11101001
0111101	00111000	−2	+2	11000111
0111110	00110100	0	0	11001011
0111111	00110010	+2	+2	11001101
1000000	00110001	+4	0	11001110
1000001	00101100	−2	−2	11010011
1000010	00101010	0	0	11010101
1000011	00101001	+2	−2	11010110
1000100	00100110	−2	+2	11011001
1000101	00100101	0	0	11011010
1000110	00100011	−2	−2	11011100
1000111	01110000	−4	−4	10001111
1001000	01101000	−2	−2	10010111
1001001	01100100	0	−4	10011011
1001010	01100010	+2	−2	10011101
1001011	01100001	+4	−4	10011110
1001100	01011000	−4	0	10100111
1001101	01010100	−2	−2	10101011
1001110	01010010	0	0	10101101
1001111	01010001	+2	−2	10101110
1010000	01001100	−4	−4	10110011
1010001	01001010	−2	−2	10110101
1010010	01001001	0	−4	10110110
1010011	01000110	−4	0	10111001
1010100	01000101	−2	−2	10111010
1010101	01000011	−4	−4	10111100
1010110	11010000	−4	0	00101111
1010111	11001000	−2	+2	00110111
1011000	11000100	0	0	00111011
1011001	11000010	+2	+2	00111101
1011010	11000001	+4	0	00111110
1011011	10110000	−6	−2	01001111
1011100	10101000	−4	0	01010111
1011101	10100100	−2	−2	01011011
1011110	10100010	0	0	01011101
1011111	10100001	+2	−2	01011110
1100000	10011000	−6	+2	01100111
1100001	10010100	−4	0	01101011
1100010	10010010	−2	+2	01101101
1100011	10010001	0	0	01101110
1100100	10001100	−6	−2	01110011
1100101	10001010	−4	0	01110101
1100110	10001001	−2	−2	01110110
1100111	10000110	−6	+2	01111001
1101000	10000101	−4	0	01111010
1101001	10000011	−6	−2	01111100

Fig.3.

iv) ± 2 Disparity Groups Pairs:

Input	Mode 1	Parity Count	d.c. Weight	Mode 2
1101010	00001100	+6	+2	11110011
1101011	00001010	+4	0	11110101
1101100	00001001	+2	+2	11110110
1101101	00011000	+6	−2	11100111
1101110	00010100	+4	0	11101011
1101111	00010010	+2	−2	11101101
1110000	00010001	0	0	11101110
1110001	00110000	+6	+2	11001111
1110010	00101000	+4	0	11010111
1110011	00100100	+2	+2	11011011
1110100	00100010	0	0	11011101
1110101	00100001	−2	+2	11011110
1110110	01010000	+4	0	10101111
1110111	01001000	+2	−2	10110111
1111000	01000100	0	0	10111011
1111001	01000010	−2	−2	10111101
1111010	01000001	−4	0	10111110
1111011	10010000	+2	+2	01101111
1111100	10001000	0	0	01110111
1111101	10000100	−2	+2	01111011
1111110	10000010	−4	0	01111101
1111111	10000001	−6	+2	01111110

Fig.3.

SPECIFICATION

Digital code for line transmission

This invention relates to a digital code for line transmission in telecommunications systems.

Binary encoding of analogue signals is an established technique for modern telecommunications systems. However, with the advent of the latest technology, such as the widespread use of coaxial cable and optical fiber line transmission systems higher and higher digital transmission speeds are being attained. Currently systems are being designed, for example, in which information is encoded for transmission at 140Mbit/sec (a "bit" being defined as one binary encoded digit, i.e. "0" or "1".).

In designing a digital line system it is important to provide for continued monitoring of performance by detection of errors produced by the system while in service. Detection of errors at the system terminal can use relatively elaborate techniques with no need to economise on power consumption.

The errors may be caused at any location along the route, e.g. by a faulty dependent repeater. The location of the source of errors for maintenance purposes can be accomplished by using at each dependent repeater a special low power consumption error detector, information from which is carried over a telemetry channel to a terminal. The location is performed most rapidly if that detector also operates whilst the system is in service; this avoids the necessity to take the system out of service when the error rate is not high enough to justify this.

One well known method of achieving in-service error detection is to use a line code which incorporates as a feature of the code itself error detection (and in some cases error correction) capabilities. A simple example of this is the use of parity control, i.e. the number of bits of a given significance must always be odd (or even) for a given digit word or block.

A recent development is the use of specially designed line codes which are different from the original information code. A typical example of this is to be found in British patent No. 1,156,279 (D.B. Waters-1), which discloses the concept of translating binary encoded information into a ternary encoded signals for the purposes of line transmission. Specifically, successive groups of N binary digits are translated into groups of M ternary digits, where M < N, such that the cumulative disparity of the ternary encoded signals does not exceed a predetermined value of either polarity. The ternary bit stream has other identifiable characteristics. For example, the longest possible block of positive or negative bits without a transition is fixed, as is the longest possible block of consecutive zeroes. This means that D.C. balance is obtained together with adequate timing content for regeneration. At the receiver the ternary groups are translated to binary independently. Because of the nature of the original translation from binary to ternary, if the accumulated disparity count in the transmitter causes ternary codes of the wrong disparity to be transmitted no digital errors are introduced in the receiver translation. Digital errors on the line only affect the actual characters mutilated, since there is no disparity count or inversion in the receiver to be upset.

A typical example of such codes is that known as 4B 3T, in which successive groups of 4 binary digits are translated into groups of 3 ternary bits. A later version of this code is known as 6B 4T.

A more recent development is the class of codes which can be generally referred to as NEMB, where N < M. Examples are 5B6B, as disclosed in British patent No. 1,250,908 and 7B8B as disclosed in British patent No. 1,540,617. The translation from NB to MB can provide signals having lower disparity that the original NB signals. The code disclosed in patent 1,540,617 is one in which successive groups of N binary digits are recoded into groups of M binary digits, where M is greater than N and both are positive integers, the recoding being arranged so that some but not all of the groups of M digits have minimum disparity and successive groups of M having non-zero disparity have disparities of opposite signs. The specific code exemplified is a 7B8B code in which the 8B groups beginning or ending with more than three like digits are excluded from use.

7B-8B coding is a good compromise between complexity and efficiency with regard to regenerability. Additionally, there is adequate redundancy to satisfy the system requirements of error detection at repeaters, error detection at terminals, short word alignment time and the provision of auxiliary channels for such uses as remote alarms and end to end Engineering Order Wire.

In determining disparity in balanced binary codes a binary one is weighted $+1/2$ and a binary zero is weighted $-1/2$ in line with CCITT vocabulary in Rec. G702. In the following text the number of consecutive ones or zeros at the beginning or end of a code word is designated "n". If it is necessary to distinguish between the beginning and the end of a code word these are designated "nb" or "ne" respectively.

In the interest of keeping the digital sum variation (DSV) small and limiting the length of consecutive ones and zeros preference is given to code words of lower disparity and smaller value of n. In the use of 7B-8B encoding it is necessary to use zero disparity, ± 1 disparity and ± 2 disparity codes words to make up the required 128 combinations. In all there are 70 possible words with zero disparity, 56 words with ± 1 disparity and 28 words with $\pm$ disparity.

Figure 1 shows a state-transition diagram for a 7B-8B code using words of zero, ± 1 and ± 2 disparity. Because the zero disparity words have an even number of marks they do not change the end of word disparity and hence the end of word parity can be associated with the end of word digital sum (DS) on the state diagram.

From Figure 1 it can be seen that the max and min end of word digital sums are $1\frac{1}{2}$ and $-1\frac{1}{2}$ respectively.

With n (zero disparity) ≤3 the max and min intra-word digital sums occur with zero disparity words as follows:

DS = −3	DS = +3
00010111	11101000
00011011	11100100
00011101	11100010
00011110	11100001
00100111	11011000
01000111	10111000
10000111	01111000

The peak digital sum can occur on either word digit 3 or 5.

If the 8 zero disparity words with 3 or more consecutive ones or zeroes in the beginning of the word are rejected it will be seen that the peak DSV of 3 can only occur at word digit 5. In addition, the maximum run of like digits, namely 7, can only occur with the last digit of the run in the word digit 4 position.

Therefore, according to the present invention there is provided a method of transmitting information encoded into a binary digit stream in which successive groups of N binary digits in the stream are translated at a transmitter into groups of M binary digits, where M > N, said translation being accomplished according to at least the following rules:-

a) only M-bit groups having a disparity of either polarity not exceeding $M/2 - 2$ are allowable.

b) no M-bit groups having more than n consecutive digits of like significance at the beginning or end of the group is allowable,

c) no M-bit group with zero disparity having more than n-2 consecutive digits of like significance at the beginning of the grop is allowable,

d) no M-bit group with zero disparity having more than n-1 consecutive digits of like significance at the end of the group is allowable.

In a preferred embodiment of the invention N = 7, M = 8 and n = 4. For this code there are a total of 136 8-bit groups available. The DSV is 6 and minimum number of transitions in each group is 2. The longest run of like digits in any two consecutive groups in 7. In a system required to convey 128 levels of speech, for example, there are 8 spare groups. This code has both the unique features referred to above, namely

7 bits of info

m,n = 7,8

1. The peak digital sum in every group occurs at the digit 5 position.
2. The maximum run of 7 like digits can only occur with the last digit of the run in the digit 4 position of a group.

With this code there are several options when the use of the spare groups is considered. Firstly, all the spare groups can be used as alternative coding to provide 8 auxiliary channels at 155 k bit/sec. This results in a parity count d.c. content of 1/232. A second option is where all the spare groups are used to maximise the parity count d.c. content, in which case no auxiliary channel is provided. In this case the parity count d.c. content is 1/40. The third option is to provide only one 155 k bit/sec auxiliary channel, the parity cound d.c. content then being 1/44.

A common method of obtaining group alignment with block codes is to check for coding rule violations (e.g. by monitoring the end-of-group digital sum). If in the initial phasing a high violation rate is measured then the relative phase of input serial data and group rate clock is slipped. This process is repeated until an alignment is obtained which gives a zero or an acceptably low violation rate. In the correct group alignment violations are only due to line errors. This method suffers from the disadvantage that, although a decoder may be in the correct alignment, a high error rate burst, due say to external interference, can cause the decoder to methodically slip through all phases before getting back to the original alignment phase which it need not have left at all. Increasing the integration time over which the error/violation rate is measured helps in this respect but gives longer re-alignment times in the event of genuine loss of alignment.

There are two methods of overcoming the above shortcoming. The first is to look for unused code groups in all phases simultaneously and choose the phase which give zero or the lowest rate of occurence of these groups. This greatly improves the resilience of group alignment to burst interference, but is somewhat cumbersome when there are 8 phases to monitor followed by the selection logic.

The second method involves organising the coding so that a particular event can be uniquely associated with group alignment. Then by inspecting the serial data stream, in the absence of line errors, group alignment can be instantly recognised without having to establish an error/violation rate. The group strategy

to combat line errors can be very similar to normal multiplex frame alignment strategy. The two unique features outlines above, viz. peak digital sum and maximum run of like digits are both particularly well suited for this purpose. The mean rates of occurrence of these unique features are:-

7 ones)
) 34 µs
7 zeros)
DS peaks of ± 3 9.5 µs
for a 140 Mbit/sec system.

The digital sum method can advantageously be combined with error detection. One alignment strategy is as follows:-

i) In the search mode So, align digit 5 of the group rate clock with the first DS of ± 3 received.

ii) Check that the next DS of ±3 also aligns with digit 5. If it does so then go into the aligned mode Ao. If it does not then realign on to this new time position and continue checking S_1 until two consecutive DS peaks occur on the same digit.

iii) In the aligned mode line errors are detected by checking for DC = ±3 occuring in digits other than digit 5. Confirmation of alignment is obtained by checking for DS = ±3 occuring in digit 5. These checks are used to implement the state diagram shown in Figure 2. It should be noted that:

i) In the absence of errors the DS peaks of ±3 can only occur in digit 5, and cannot be simulated by traffic.

ii) In the presence of errors each error indication is in general accompanied by a confirmatory alignment indication. This property gives the alignment very high immunity against errors.

A typical 7B8B code translation table is illustrated in Figure 3.

Whilst no specific hardware implementation for the invention has been given it will be apparent to those skilled in the art that conventional digital data handling technology can be employed, the necessary adaptions for the particular codes to be used being quite straightforward.

CLAIMS

1. A method of transmitting information encoded into a binary digit stream in which successive groups of N binary digits in the stream are translated at a transmitter into groups of M binary digits, where M > N, said translation being accomplished according to at least the following rules:-

a) only M-bit groups having a disparity of either polarity not exceeding $^{M}/_{2}$ – 2 are allowable,

b) no M-bit groups having more than n consecutive digits of like significance at the beginning or end of the group is allowable,

c) no M-bit group with zero disparity having more than n-1 consecutive digits of like significance at the end of the group is allowable,

d) no M-bit group with zero disparity having more than n-1 consecutive digits of like significance at the end of the group is allowable.

2. A method according to claim 1 wherein N = 7, M = 8 and n = 4.

3. A method of transmitting digital data substantially as hereinbefore described with reference to the accompanying drawings.

4. A digital data transmission system wherein data is transmitted by the method claimed in any preceding claim.

5. A transmitter for transmitting information by the method claimed in any one of claims 1 to 3.

6. A receiver for receiving information by the method claimed in any one of claims 1 to 3.

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